The Robotic Technology Applications on Nuclear Power Plants in Korea

Seungho Kim* and Chang-Hwan Choi* *Nuclear Robotics Lab., Korea Atomic Energy Research Institute

1. Introduction

Nuclear energy has become a major energy source to worldwide, even though we are still debating the environmental and safety aspects. In order to cope with that issues related to the nuclear power plants, the uncertain human factors need to be minimized by automating the inspection and maintenance work done by human workers. The demands of a robotic system in the nuclear industry have been growing to ensure the safety of nuclear facilities, to detect early an unusual condition of it through an inspection, to protect the human workers from an irradiation, and to maintain it efficiently.

NRL (Nuclear Robotics Laboratory) in KAERI (Korea Atomic Energy Research Institute) has been developing robotic systems to inspect and maintain nuclear power plants in stead of human workers for over thirteen years. In order to carry out useful tasks, a nuclear robot generally requires the followings. First, the robot should be protected against radiation. Second, a mobile system is required to access to the working area. Third, a kind of manipulator is required to complete the tasks such as handling radioactive wastes and other contaminated objects, etc. Fourth, a sensing system such as cameras, ultrasonic sensors, temperature sensors, dosimetry equipments etc., are required for operators to observe the work place. Lastly, control systems to help the operators control the robots. The control system generally consists of a supervisory control part and a remote control part. The supervisory control part consists of a man-machine interface such as 3D graphics and a joystick. The remote control part manages the robot so that it follows the operator’s command.

This paper provides an introductory statement of the robotic systems developed in NRL and introduces a kind of mobile robot that includes general purpose mobile platforms, which have an articulated manipulator or mast mechanism. Several applications has been described for underwater robot to inspect a reactor vessel, small mobile robot with cameras for a reactor exterior inspection, and an inch-worm style robot for a feeder pipe inspection. Two manipulators has been described for the inspection of a steam generator tube with an eddy current sensor system, and an articulated robot utilizing hydraulic powers.

2. Mobile Robots

2.1 Mobile Platform

Safety related equipment of the Reactor Coolant System (RCS) has to be monitored and maintained to ensure the nuclear plant’s efficiency, availability and integrity from a thermal loading, vibrations, and various types of corrosion. RCS maintenance work conducted during a plant refueling outage involves complex tasks and the environment is inherently hazardous because of a high radiation level and contamination. Therefore, a series of mobile robots named as KAEROT have been developed to maintain RCS [1][2]. KAEROT series is a multi-functional mobile system for the inspection and maintenance of a primary system in a nuclear power plant. It consists of a mobile system, a manipulator or a mast mechanism and sensory systems. The mobile systems are designed to have the features of a modularity, reliability as well as a stability. KAEROT in Fig. 1 (a) is a four planetary-wheeled mobile robot capable of ascending and descending stairs and navigating a flat surface with a zero turning radius. KAEROT/ml in Fig. 1 (b) has planetary wheels with three small omni directional wheels that have six elliptical shaped rollers which make it possible to move in any directions. A manipulator is mounted on top of the mobile system
The Robotic Technology Applications on Nuclear Power Plants in Korea

Fig. 1 KAEROT series mobile robots which has six DOFs. The electrical-driven manipulator is designed to handle a 5 [kg] payload at the end-effector at full length, with a resolution of 0.3 [mm] on all axes for a fine positioning of the end-effector. KAEROT/m2 in Fig. 1 (c) and (d) is especially designed for inspecting the Calandria, a front side of PHWR, when the reactor is in operation. It has a wheel-drive mechanism with four tracks to climb and pass through obstacles. The 10 meter-long mast mechanism enables it to inspect the pressure tubes and feeder pipes precisely by an infrared camera.

2.2 Underwater Robot for Reactor Vessel Inspection

The presence of loose parts in the primary coolant system can be an indication of a degraded reactor safety resulting from a failure or weakening of safety-related components. A loose part, whether it is from a failed or weakened component or from an item inadvertently left in the primary coolant system during construction, refueling, or maintenance such as loose metallic parts, bolts, nuts and washers can contribute to component damage and material wear by a frequent impacting with other parts in the system. A loose part increases the possibility for a control rod jamming and for an accumulation of increased levels of radioactive crud in the primary coolant system. NRL has been developing robotic systems to inspect the reactor head as shown in Fig. 3 (a). The robot can move between CRDM and is attached to the reactor head surface by using a magnetic wheel to prevent it from skidding. Fig. 3 (b) shows the reactor bottom inspection robot, which has a high resolution pan/tilt camera and three additional cameras with a different view angle. The slave robot shown in Fig. 3 (c) observes the movement of the main robot and helps the robot operator to control it easily.

2.3 Reactor Exterior Inspection Robot

The PLWR (Pressurized Light Water Reactor) has CRDM (Control Rod Drive Mechanism) nozzles at the reactor head and many instrumental nozzles at the bottom of the reactor. The former houses of CRDM that regulates the power output of the reactor and the latter has the sensors to detect the neutron emission and temperature of the reactor.

In 2002, CRDM nozzle leaks were discovered in several nuclear plants in united states, which raised the need for an inspection of the reactor head. The primary method for detecting leaks from the CRDM head penetration nozzle is to perform a visual examination of the welding part at the nozzle and head intersection. Any areas that exhibit characteristic “white deposits” are indicative of a boron salt residue coming from a primary coolant leak. The bottom part of a reactor has similar inspection method with a different working environment.

NRL has been developing robotic systems to inspect the reactor head as shown in Fig. 3 (a). The robot can move between CRDM and is attached to the reactor head surface by using a magnetic wheel to prevent it from skidding. Fig. 3 (b) shows the reactor bottom inspection robot, which has a high resolution pan/tilt camera and three additional cameras with a different view angle. The slave robot shown in Fig. 3 (c) observes the movement of the main robot and helps the robot operator to control it easily.

2.4 Feeder Pipe Inspection Robot

The outlet feeder pipe thinning in a PHWR (Pressurized Heavy Water Reactor) is caused by a high pres-
sure steam flow inside the pipe, which is a well known degradation mechanism called FAC (Flow Assisted Corrosion). In order to monitor the degradation, the thickness of the outlet bends close to the exit of the pressure tube should be measured and analyzed at every official overhaul. However, collecting high quality data is a challenge, mainly due to a lack of space around the pipes, especially for 2.5 inch pipes and the roughness of the feeder pipes. Moreover, although the reactor is shutdown in the overhaul period, the radiation dose is severe near the feeder pipe because they are located in front of the reactor.

NRL has been developing a mobile feeder pipe inspection robot that automatizes the measurement process. As shown in Fig. 4, the robot can move by itself on the feeder pipe by using an inch worm mechanism, which is constructed by two gripper bodies that can fix the robot body on to the pipe and one extension/contraction actuator and a rotation actuator connected to the two gripper bodies, which move to axial direction and rotate in a circumferential direction of pipes. These actuators are driven pneumatically which are embedded inside the robot body to reduce the size and weight of the robot, so that it is applicable to feeder pipes of PHWR (Pressurized Heavy Water Reactor).

3. Manipulators

3.1 Steam Generator Inspection and Maintenance Robot

Steam generators of a nuclear power plant are heat exchangers which are internally in contact with the primary coolant and externally in contact with the secondary coolant which goes to the turbine generator. The steam generator has nearly 8,000 tubes for heat exchange. The tubes are welded into a thick tube seat that encloses the upper hemisphere of the plenum. The integrity of the tube influences the degree of the radioactive contamination appearing on the secondary side. Therefore, the inspection and maintenance of the steam generator tubes are one of the most important processes for its safety.

NRL developed a radiation hardened robotic system to assist in on automatic non-destructive testing and repair of nuclear steam generator tubes without human workers in the plenum [4] [5]. Eddy-current testing and an evaluation technique are used to validate the integrity of the tubes as shown in Fig. 5. The robotic system consists of five DOFs robot manipulator, multi-axis robot controller, sensor control and data acquisition system, and the robot host controller. The robot manipulator has a scalar type with two DOFs robot manipulator and three DOFs trunk mechanism for adjusting the position and orientation of the manipulator. Industrial multi-axis motor controller and driver is used for the local controller, and a windows based host control program is developed, assisted by 3D graphics, which helps the robot operator.

3.2 Nozzle Dam Installation and Removal Robot

The nozzle dam installation/removal robotic system was developed to perform an unmanned nozzle dam installation and removal tasks inside a steam generator water chamber from a remote site [6]. This system consists mainly of two master/slave with six DOFs manipulators, a supporting device and a monitoring system. The slave manipulator is driven by a hydraulic manipulator and is designed to have a capacity of a 60 [kg] pay load to carry the nozzle dam at the end-effector.
4. Conclusions

This paper introduced the robotic systems developed in NRL for the nuclear industry. Several kinds of mobile robots and manipulators were introduced such as a general purpose mobile platform, an underwater robot, small mobile robots, an inch-worm mobile robot, steam generator inspection robot, and an articulated hydraulic powered robot.

Since the energy policy of the countries worldwide are concerned mostly with the environmental issues which will be a major factor in the near future, the need for nuclear energy has increased. Thus, a robotic system that is closely related to the enhancement of the safety and integrity of both the power plant and the workers will have an important position in the nuclear industry.

Acknowledgements This paper is supported by the Korea Atomic Energy Research Institute as a project of “The Development of Radiation Hardened Robot for Nuclear Facility" sponsored by the Ministry of Science and Technology, Korea.

References

Seungho Kim
Seungho Kim was born in Inchon, Korea, on June 15, 1953. He received the B. S. degree in mechanical engineering in 1979 from Yonsei university, Seoul, Korea, and Ph. D. degree from the same graduate school in 1988. Since 1980, he managed the Nuclear Robotics Lab., in the Korea Atomic Energy Research Institute. His interest currently related to robotic system, vision, radiation hardening techniques, sensor system.

Chang-Hwan Choi
Chang-Hwan Choi was born in Jinhae, Kyungnam province Korea, on February 10, 1973. He received the B. S. degree in precision mechanical engineering in 1995 from Hanyang university, Seoul, Korea, and Ph. D. degree from the Gwangju Institute of Science and Technology in 2001, which is a government supported graduate school, in Gwanju, Korea. Since 2001, he worked in the Nuclear Robotics Lab., in the Korea Atomic Energy Research Institute. His interest currently related to robotic system, embedded system, vision, sensor system, and so on.